Advances in Technology at the
National Renewable Energy Laboratory

Technology Brief

Profits from Old Plastics

NREL's Selective Pyrolysis Recycles Nylon Carpeting, Car Parts, and Other Plastics

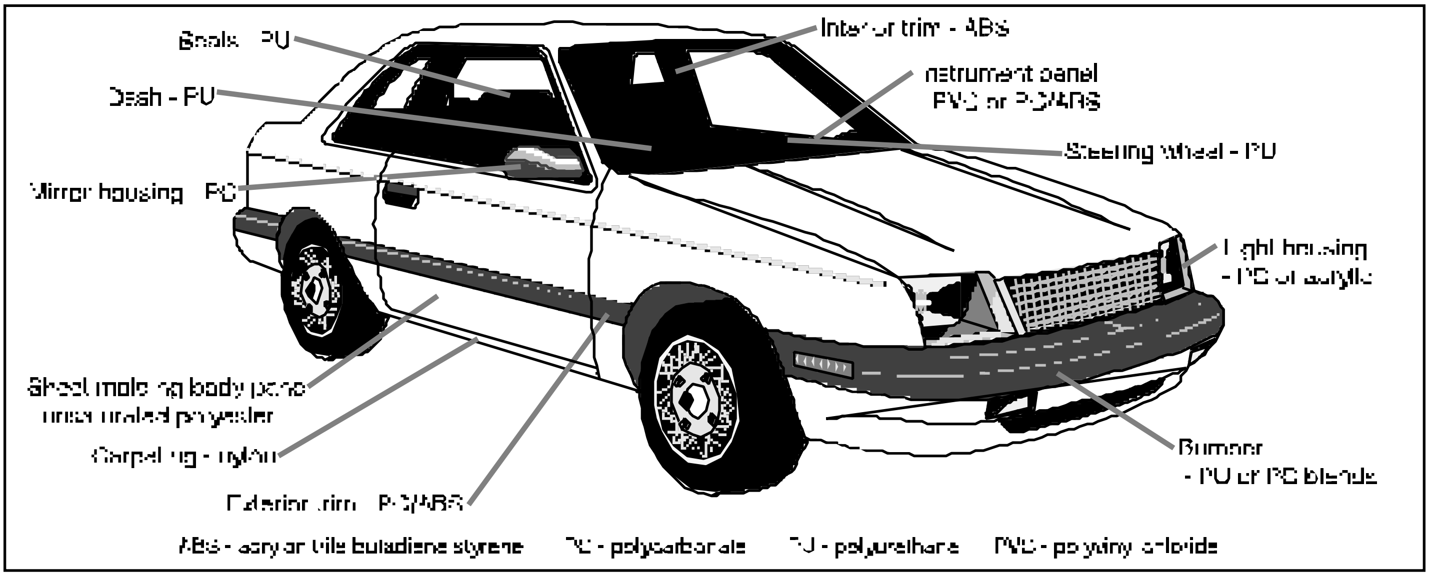
You have heard the complaint many times: "Plastics epitomize our 'throw-away society.' They are filling our landfills, and will be there forever." Another frequent criticism is that we rely on imported oil to produce those plastics. Will public concern over inability to recycle plastics lead to onerous regulations?

Some technologies mechanically recycle plastics or burn them as fuel, but wouldn't it be better if we could recover and reuse the valuable chemicals that go into those plastics? The U.S. Department of Energy's National Renewable Energy Laboratory (NREL) has developed technology that can do just that for many mixed polymer wastes. These include nylon carpeting, engineering blends, and a potentially wide range of other plastics from industrial scrap or consumer trash. With selective pyrolysis, NREL scientists can separate and recover the different base chemicals from which used plastics were made—even if the resource material is a soup mix of assorted plastics.

Already NREL is teaming up with the Fibers Division of AlliedSignal Inc. to evaluate selective pyrolysis for industrial-scale recycling of nylon 6 carpeting—about 30% of the carpeting sold in the United States. (Nylon and many other synthetic fibers are plastics—polymers of building block monomers linked into chains to form giant molecules.) From used carpeting, selective pyrolysis can recover the base monomer, caprolactam, that AlliedSignal uses to make nylon 6. NREL estimates that the process will use less than a third of the energy required to make caprolactam from petroleum and will cost less than a third of the current selling price of the chemical.

The key breakthrough is that different plastic monomers are removed separately–even if the resource material is a mixture.

Selective pyrolysis uses the heat of a fluidized-bed reactor and catalysts in the absence of oxygen to pyrolyze



NREL's selective pyrolysis process can chemically recycle a myriad of used plastics including those used in today's cars.

plastics (see sidebar on page 3). The key breakthrough solves the problem of mixed plastics. On the basis of precise analysis of the components of a mixture, NREL scientists can carefully set conditions to remove one plastic at a time from that mixture.

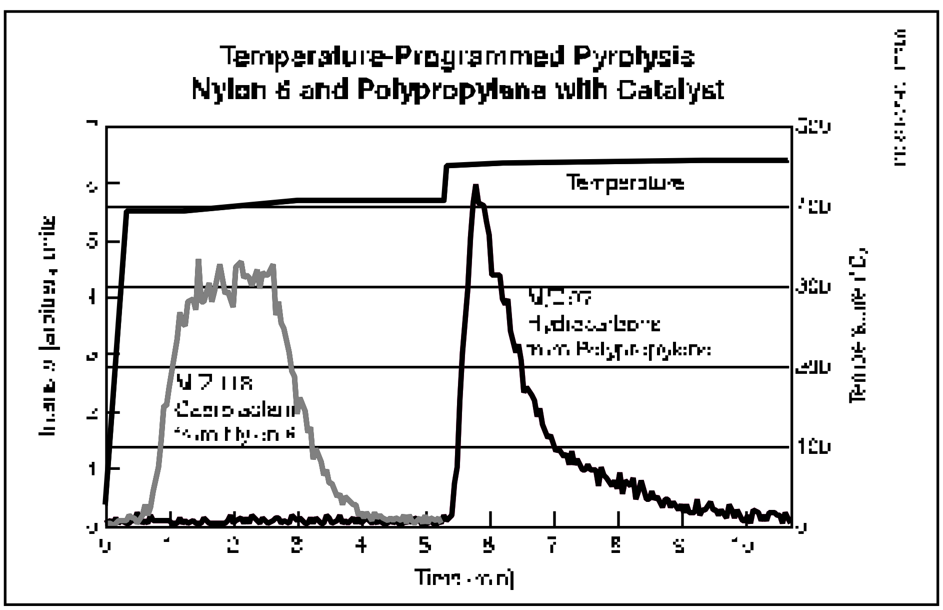
Nylon Carpet Recycling Shows Great Promise

NREL's accord with AlliedSignal to recycle nylon 6 carpeting is a cooperative research and development agreement (CRADA). CRADAs are a key way NREL works with industry to bring promising technologies into readiness for commercial use. AlliedSignal will prepare the used carpet feedstock, purify the end product, and do engineering assessments of the process for commercial-scale production.

NREL has subcontracted with a private engineering research firm to scale up selective pyrolysis from the current 1 kilogram per hour (kg/h) feedstock reactor to one that can handle 50 kg/h. That process development unit will be used to thoroughly test the technology on nylon 6 and evaluate commercial prospects. One of the main goals for NREL researchers is to further improve the selectivity of the process for caprolactam. This would reduce the need for subsequent product purification and would further improve process economics.

Researchers expect to be able to selectively pyrolyze caprolactam from used carpet for $0.33-$0.66/kg ($0.15-$0.30/lb), depending on collection costs. (Caprolactam prices vary, but are currently about $2.00/kg [$0.90/lb], more than three times as much.) Selective pyrolysis should also be less expensive than other chemical recycling methods that require mechanically removing the polypropylene backing from the carpeting.

The process promises to use less than a third as much energy as making caprolactam from petroleum and cost less than a third of the chemical's current selling price.



NREL's selective pyrolysis technique separates the high-value chemical caprolactam from the mixture of plastics in nylon 6 carpeting by carefully controlling pyrolysis conditions, as shown in this graph of product formation over time.

Photo to come later

Selective pyrolysis utilizes a fluidized bed reactor (front left). This laboratory system, which handles 1 kg/h of waste plastic is being scaled up to a process development unit able to handle 50 kg/h.

Prospects for chemically recycling nylon 6 carpeting are excellent because of several factors. Used carpeting is easy to collect, caprolactam is a high-value commodity chemical, and selective pyrolysis works well on both nylon 6 and the polypropylene backing material. An independent economic evaluation projected that a commercial-size plant producing 45 million kg (100 million lb) of caprolactam per year from waste carpet could recover its initial capital investment within 1 year.

Car Parts and Other Plastics

Nylon 6 should be just the beginning. The advice given to Dustin Hoffman in *The Graduate* ("I have just one word for you Benjamin—plastics.") was by no means bad advice. U.S. demand for plastics is expected to reach 34.5 billion kg (76 billion lb) per year by 2000. Already 14 billion kg (30 billion lb) of plastic end up in landfills each year. We are now recycling only 1% of our discarded plastics.

The economics of selective pyrolysis should also be excellent for other high-cost plastics, particularly engineering blends such as

Solving the Problem of Plastics: How Selective Pyrolysis Works

The primary problem with plastic recycling is that different plastics get mixed together—at the molecular level in blends and compounds, in products with assorted parts made of various plastics, and in municipal solid waste. Even where different plastics can be physically separated, the high cost of such presorting might preclude recycling. Increasing use of "engineered" plastics, with their higher cost and inherent mix of diverse plastics, intensifies both the difficulty and the potential benefit of plastic recycling.

Pyrolysis transfers large amounts of heat to materials in the absence of oxygen to break them down into simpler compounds. Pyrolysis has been previously investigated for plastic recycling, but usually just for producing fuel, without any effort to separate assorted plastics for their chemical value. NREL's selective pyrolysis process carefully controls temperature, catalysts, and other conditions so that only one plastic at a time pyrolyzes to monomers or related compounds in the gaseous phase. After that vapor is removed for recovery, conditions are changed so that the next plastic pyrolyzes. This sequential pyrolysis and removal separates pure fractions of the various plastic building blocks that, depending on their value, can then be used to make new plastic materials or be used for fuel for process energy.

Selective pyrolysis owes much of its success to molecular beam mass spectrometry (MBMS) (see photo caption at right). NREL scientists use MBMS to identify the specific components of a plastic mixture and determine the conditions under which they can be selectively converted to valuable chemical compounds. They then further analyze the chemical pathways of the pyrolysis and determine precise temperatures and catalyst concentrations to most effectively separate out the desired plastic building blocks.

With the strategy designed for a particular feedstock, operators shred or melt the "raw" plastic and inject it into the pyrolysis reactor. The particular plastic for which conditions have been set turns to gas when it hits the fluidized bed of the reactor. That gaseous monomer is removed from the reactor, condensed and recovered. Operators then adjust conditions so that the next plastic will pyrolyze. Ideally, in a continuous industrial operation, the molten plastic would flow from one set of conditions to the other with gaseous monomer being extracted from each "subreactor."

Photo to come later

The molecular beam mass spectrometer (MBMS—transportable version shown here) allows NREL scientists to determine proper conditions to convert plastic waste back into chemical resources. It can also be used to control, monitor, and analyze many other thermochemical processes. Unlike other analysis methods, MBMS provides instantaneous analysis and does not risk modifying material composition in the sampling process.

polycarbonate (uses include automotive taillight covers and safety "glass") and acrylonitrile butadiene styrene (ABS, which is used for automotive trim parts, appliances, canoes, and other sporting goods). NREL has already done development work on selective pyrolysis of polyurethane (used for seat cushions and upholstery in furniture and cars and in many other flexible and rigid auto parts), separating out the two different chemicals from which it is made. NREL is eager to negotiate cooperative agreements with interested industries to develop selective pyrolysis technology for these and other plastics. As emphasis on fuel efficiency further multiplies the amount of plastic—particularly higher value plastic—used in automobiles, junkyards could become increasingly rich mines for selective pyrolysis ore.

High volumes of the more common plastics may make their recycling necessary from the standpoint of waste disposal, even if the cost of source chemicals does not. Selective pyrolysis can fill that need as well, producing more valuable end products than other ways of recycling would. For example, NREL researchers have selectively pyrolyzed mixed plastic bottles to recover dimethylterephthalate, the monomer for polyethylene terephthalate (PET), the plastic used for most beverage containers. Further work may improve economics for this highly visible recycling need.

NREL is eager to negotiate cooperative agreements with interested industries to develop selective pyrolysis processes for various plastics.

Future Waste Management Policy Could Compel Recycling

In the future, communities faced with landfill shortages and high waste-management costs might mandate that bulky, identifiable, or slow-to-decompose items (such as plastic) be returned to their manufacturer. Recycling technologies such as selective pyrolysis would prove immensely valuable under such a policy. Manufacturers would also have a strong incentive to choose materials that recycle well. With commercialization of selective pyrolysis of nylon 6–and economics as attractive as they are expected to be–no compulsion would be needed to begin retrieving waste carpeting. Plastic recycling by selective pyrolysis has tremendous potential to make a visible and important contribution to reducing the need for oil and for landfills.

Photo to come later

David Humber

Waste carpeting, a significant landfill component, could be recycled with a new NREL technology.

Publications and Patents

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